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Contract NASW-98

ELECTRON DENSITY IN THE IONOSPHERE

Quarterly Engineering Progress
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1. INTRODUCTION

The construction of two payloads for Nike-Asp rocket flights are now complete and the instrumentation is being given final testing and calibration. The first payload will be fired from Wallops Island, Virginia, on June 2, 1960.

Part of the purpose of this experiment consists in comparing the performance of two electrodes located on the surface of the payload section. The two locations chosen for the electrode are the tip of the conical nose section (nose electrode) and a disc flush with the surface of the cylindrical section of the payload (side electrode). [These positions have been indicated in Figure 1 of Progress Report No. 1.] It is felt that the nose electrode will be less subject to disturbances arising from the rocket itself particularly at altitudes below 100 km and provides the possibility of detecting shock-wave ionization when second stage rocket reaches a maximum Mach Number of 7.5 at burnout. The side electrode, however, will be more sensitive to rocket attitude and should show a modulation of the signal coinciding with the spin of the rocket.

2. THE NOSE ELECTRODE

The nose electrode presents the greater design problem. The normal practice with this type of sensing element has been to provide a protective cover which is jettisoned at some pre-determined height, usually not less than 50 km. This was felt to be undesirable in the present case as it added to the complexity of the instrumentation and excluded the possibility of obtaining measurements in the lower atmosphere.

The configuration adopted for the nose electrode (and for that matter the side electrode) maintains the original external shape of the payload. The nose electrode is a right circular cone of half angle 5° 30' and 10 in. high made of stainless steel. This piece weighs nearly 3 pounds and is to be insulated from the body of the rocket by at least 10^{3} ohms. An early design of the method of supporting and insulating the electrode is shown in Figure 1 and the final design in Figure 2.

The insulator, in the form of a truncated cone 2 in. high, is made of an impervious ceramic (99.9 percent pure alumina). Three grooves 1/16 in. wide x 1/8 in. deep increase the leakage path. In the original design, Figure 1, the ceramic is bonded to stainless steel, the central rod being merely to provide electrical contact with the electrode. This design is mechanically unsatisfactory, however, due to the relatively low strength of ceramic when subject to tension. The design which was finally adopted does not use any bond and the ceramic is always under compression, never tension.

In the final design, Figure 2, the assembly is held together by a large bolt which is seen in the center of the diagram. This bolt is first clamped to the rear stainless steel piece, from which it is insulated by two fiberglass washers. The upper fiberglass washer also establishes the axial position of the ceramic insulator. Copper shims, 0.005 in. thick, are placed between ceramic and steel and finally the conical electrode is screwed into position. The weight of the whole assembly is 5 pounds. The surface area of the nose electrode is 196 cm^2 which is about 1/100 of the total surface area of the Asp vehicle (motor and payload).

3. THE SIDE ELECTRODE

The design of the side electrode presents less difficulty due to the less stringent environmental conditions, particularly that of temperature. The electrode itself is a stainless steel disc 2 in. diameter and 1/16 in. thick which is rolled to match the curvature of the vehicle (6.50 in. outside diameter). This is located in an aperture in the side of the rocket with an insulator filling the gap, 1/4 in. wide, between the electrode and the rocket skin. In order to conserve space within the payload section and to provide a good pressure seal, it was decided that the electrode assembly would be made a permanent part of the payload skin. The construction of the rocket is such that no part of the side electrode assembly must project more than 3/16 in. inside the skin. Two possible methods of construction were tried and both developed successfully; one uses an epoxy casting resin (Emerson and Cummings, Stycast 2762) while the other uses Teflon. The latter has been chosen for the first rocket. The casting resin is molded in place being anchored to the skin and to the electrode by a series of knurled nuts embedded in the compound. Physically the material is very satisfactory but from a practical point of view has the disadvantage of requiring to be molded in vacuum (to eliminate air bubbles) and a subsequent cure at elevated temperature. Both operations require special equipment and are felt to detract from the flexibility of the method. The other method, using teflon, is more easily adapted to other vehicles should the opportunity arise for "hitch-hiking."

4. FUTURE WORK

A proposal has been submitted for continuation of the present program of rocket flights. Three specific experimental investigations are suggested:

(a) Measurement of the photoelectric emission from the rocket surface as a function of height, with particular reference to the effect of this current on the interpretation of Langmuir probe observations.

(b) A study of the electron density distribution during occurrence of a polar blackout and its relation to soft auroral radiation, by simultaneous use of Langmuir probe and thin-walled Geiger counters.

(c) Measurement of electrical conductivity in the altitude region 30-90 km by a double probe method of conductivity measurement. The theory of the method has recently been developed and an outline is given in the following section.

5. DOUBLE PROBE MEASUREMENT OF CONDUCTIVITY

The rocket carrying an electron probe is, in general, not at the same potential as the plasma in which it is immersed. This leads to the so-called "floating double probe" method of measurement, developed by Johnson and Malter for the Langmuir probe, and derived below for conductivity measurements.

Consider a double probe system, Figure 3a, consisting of a small spherical electrode S_1 and a large spherical electrode S_2, immersed in a plasma with polar conductivities σ_- and σ_+. A potential V is applied between the electrodes (the polarity being such that the small electrode is positive with respect to the large electrode) and a current I observed to flow between them. V and I are the two quantities measured experimentally.

The current of negative ions (including any electrons) into S_1 must equal the current of positive ions into S_2. An equilibrium condition is reached at which S_1 is at a potential V_1, and S_2 at a potential V_2, both measured with respect to the plasma potential; V_1 being positive and V_2 negative, Figure 3b. Thus

$$V_1 - V_2 = V \tag{I.1}$$

By a theorem in electrostatics, if an electrode (of arbitrary shape) having a capacity C is immersed in a medium of conductivity σ, then, in the absence of space charge (electrode effect), the resistance R (potential divided by current into the electrode) is given by

$$C\,R = \frac{1}{4\pi\sigma} \tag{I.2}$$

This may be easily verified for the case of a spherical electrode.

In the double probe system, we have, therefore, at electrode S_1,

$$\frac{C_1 V_1}{I} = \frac{1}{4\pi\sigma_-} \tag{I.3}$$

where C_1 is the capacity of the isolated electrode S_1. Similarly for electrode S_2

$$-\frac{C_2 V_2}{I} = \frac{1}{4\pi\sigma_+} \tag{I.4}$$

where C_2 is the capacity of the isolated electrode S_2.

Combining (I.3) and (I.4)

$$\frac{V_1}{V_2} = \frac{C_2}{C_1} \cdot \frac{\sigma_+}{\sigma_-} \tag{I.5}$$

Thus, from I.1

$$V_1 = \left(\frac{C_2\ \sigma_+}{C_2\sigma_+ + C_1\sigma_-}\right) V \tag{I.6}$$

$$V_2 = \left(\frac{C_1\ \sigma_-}{C_2\sigma_+ + C_1\sigma_-}\right) V \tag{I.7}$$

Substituting I.6 in I.5 and rearranging, we obtain, finally,

$$\left(\frac{I}{V}\right)_+ = \frac{4\pi C_1 C_2 \sigma_+ \sigma_-}{C_2\sigma_+ + C_1\sigma_-} \tag{I.8}$$

The subscript is added to the ratio (I/V) to indicate this formula applies to positive values of V. The corresponding equation for negative values of V is

$$\left(\frac{I}{V}\right)_- = \frac{4\pi C_1 C_2 \sigma_+ \sigma_-}{C_1\sigma_+ + C_2\sigma_-} \tag{I.9}$$

If the ratio (I/V) is measured for positive and negative values of V and C_1 and C_2 are known (but unequal), it is possible to obtain σ_+ and σ_-

using equation I.8 and I.9. This is the basis of the double probe measurement of conductivity.

Two special cases are of particular interest:

(a) When σ_+ and σ_- are approximately equal (as when $\lambda = N_- / N_e$ is very large), then, assuming $C_2 \gg C_1$, the slopes of the I-V plots become

$$\left(\frac{I}{V}\right)_+ = 4\pi C_1 \sigma_- \qquad (I.10)$$

and

$$\left(\frac{I}{V}\right)_- = 4\pi C_1 \sigma_+ \qquad (I.11)$$

Thus the positive and negative polar conductivities may be measured separately and only C_1 need be known accurately.

(b) When σ_- is much greater than σ_+ (as when λ is small), the equations become, approximately,

$$\left(\frac{I}{V}\right)_+ = 4\pi C_2 \sigma_+ \qquad (I.12)$$

$$\left(\frac{I}{V}\right)_- = 4\pi C_1 \sigma_+ \qquad (I.13)$$

In this case, for either polarity, the current is determined by the positive polar conductivity and the negative conductivity is not measured.

It will be noted that the slope for negative voltages is the same whether the negative component of the plasma consists of negative ions or electrons (or both). Thus the value of positive polar conductivity may be experimentally determined without any knowledge of λ for the plasma.

It is possible that the composition of the plasma may be determined by considering the ratio $(I/V)_+ / (I/V)_-$:

For (a) (no electrons):

$$\frac{(I/V)_+}{(I/V)_-} = \frac{\sigma_-}{\sigma_+}$$

Whereas for (b) (no negative ions):

$$\frac{(I/V)_+}{(I/V)_-} = \frac{C_2}{C_1}$$

The latter is a (known) constant of the experiment. Thus a comparison of slopes for positive and negative voltages provides an experimental method of distinguishing the two cases and perhaps of evaluating λ.

The theory predicts a linear current-voltage characteristic, although with different slopes for positive and negative voltages. It is to be expected, however, that in practice this will be true only for sufficiently small currents. For larger currents the formation of space charge at the electrodes will reduce the slope. The characteristics will thus become curved as though towards a saturation current though not reaching one. An analysis of such an electrode effect by J. J. Thompson leads to a relation of the form

$$V = A\,I + B\,I^2$$

which is linear for small I but parabolic for large I.

Another important factor to be considered is the effect of photoemission from the surface of either electrode. The magnitude of the effect is not known with certainty, but in the O-region is probably about 2 x 10^{-9} amp per cm^2 for a surface normal to the solar radiation. This current flows when the electrode is negative with respect to space potential. The photoelectric current I_e (from the negative electrode) can easily be incorporated in the theory given above. The result is that the current-voltage characteristic is now broken into two linear parts corresponding to $I \gg I_e$ and $I \ll I_e$, Figure 4. For $I \gg I_e$ the slope is as given before (I.8), while for $I \ll I_e$ the slope is greater, being

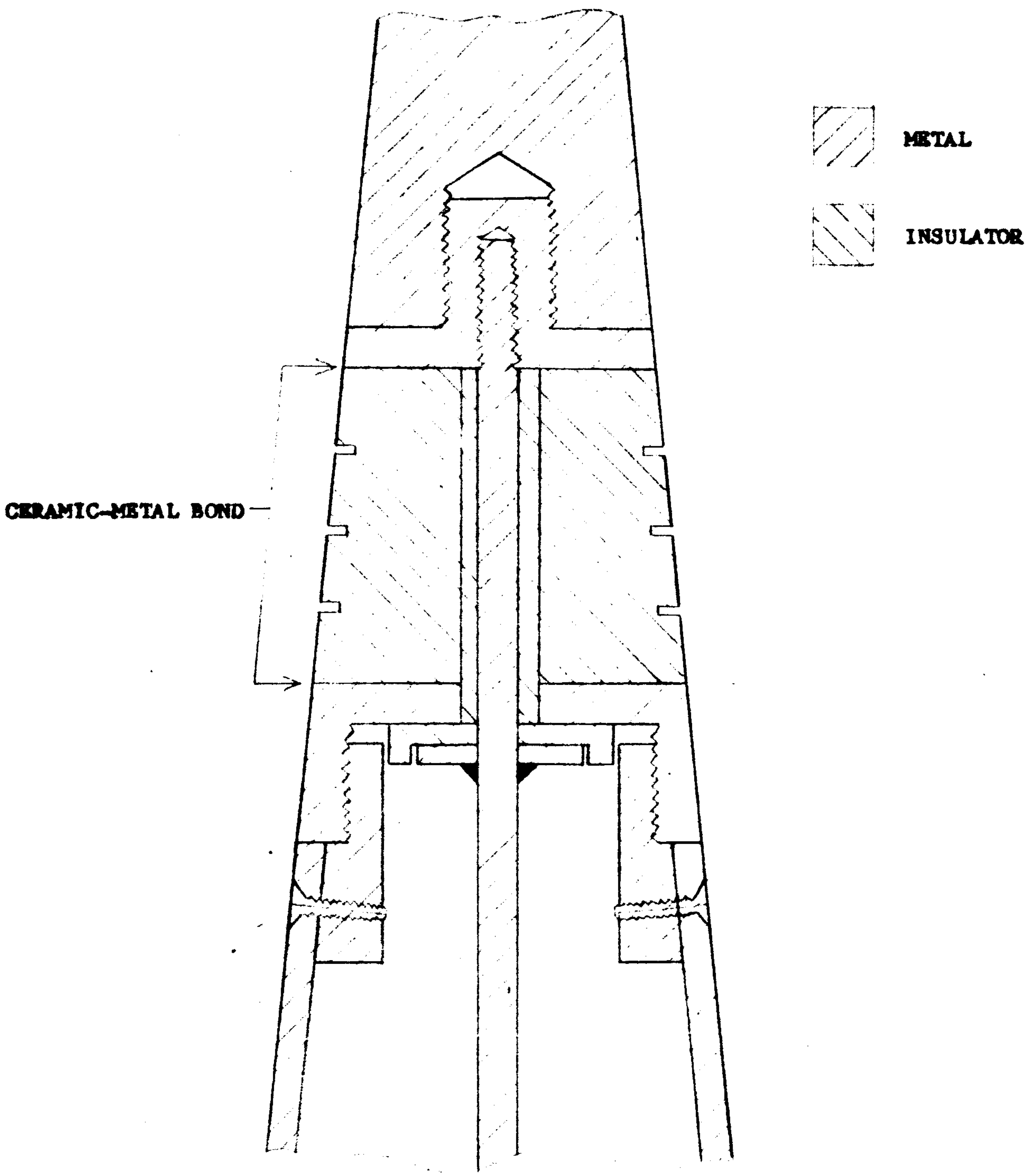
$$\left(\frac{I}{V}\right)_+ = 4\pi C_1 \sigma_-$$

Again, these relations must be modified to incorporate the electrode effect.

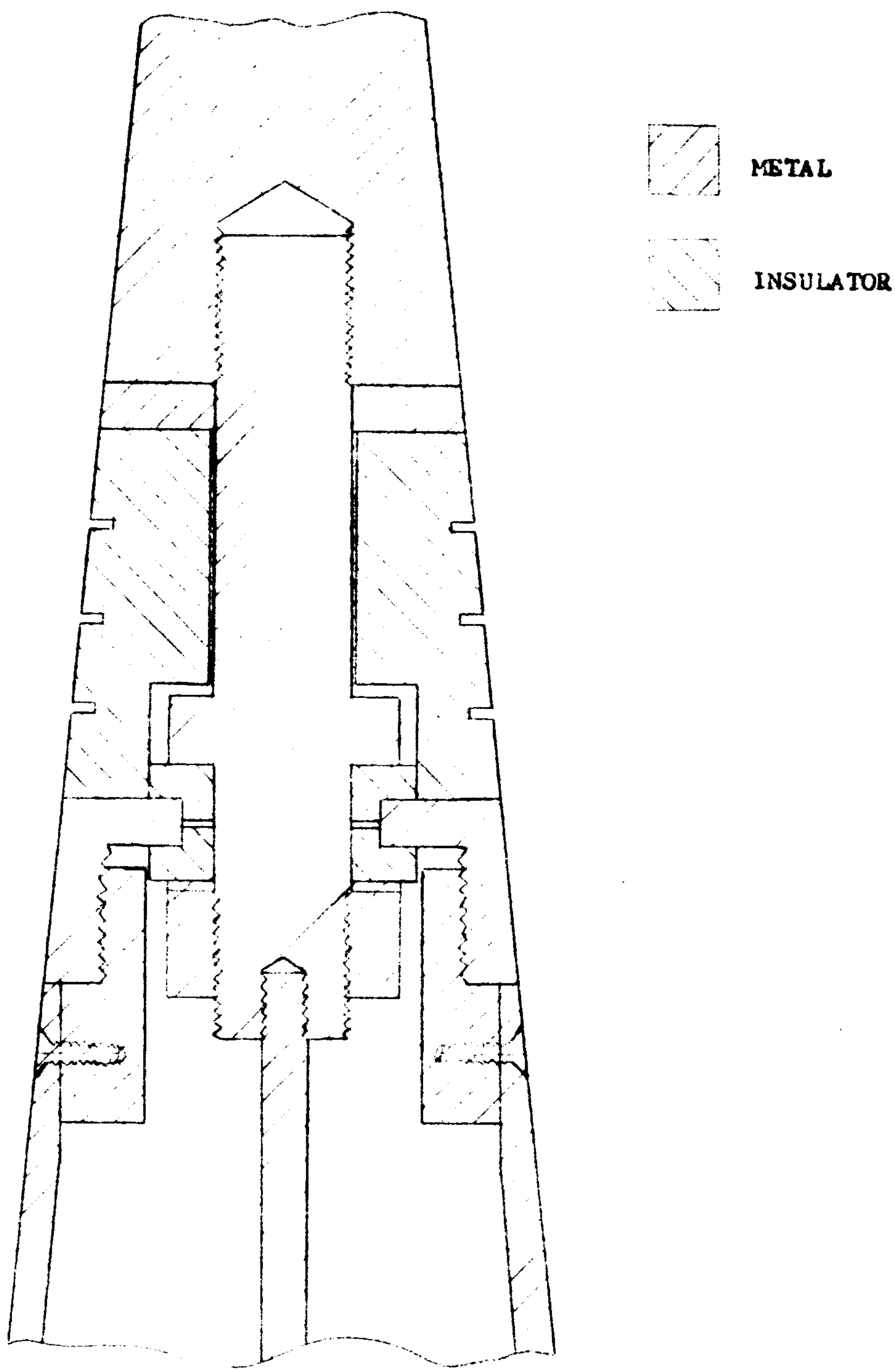
The analysis has been presented above for unequal spheres physically separated but electrically connected. This geometrical arrangement is inconvenient for rocket launch especially if measurements are to be made below the D-region where atmospheric drag is considerable. It is proposed to use the double-probe conductivity method with the electrode arrangement already developed for the Langmuir probe experiment. In this the major part of the payload section and rocket motor casing form the larger electrode while the small electrode is alternately either a circular disc (5 cm diameter) in the rocket skin or the top 25 cm of the nose cone. In this arrangement the aerodynamic shape of the rocket is preserved and a relatively simple construction evolved.

This geometrical arrangement makes for complication in determining the appropriate values of capacity to be substituted in equations (I.8) and (I.9). A rough value can be obtained by assigning a characteristic length to each electrode, an average radius. For more accurate work, a calibration experiment must be performed by inserting the rocket in a wind tunnel or by using a model in an electrolytic tank. Initially, however, the validity of the technique can be tested by studying the variation with height of the (I/V) slopes for positive and negative voltages. This experiment can conveniently be combined with a Langmuir probe experiment.

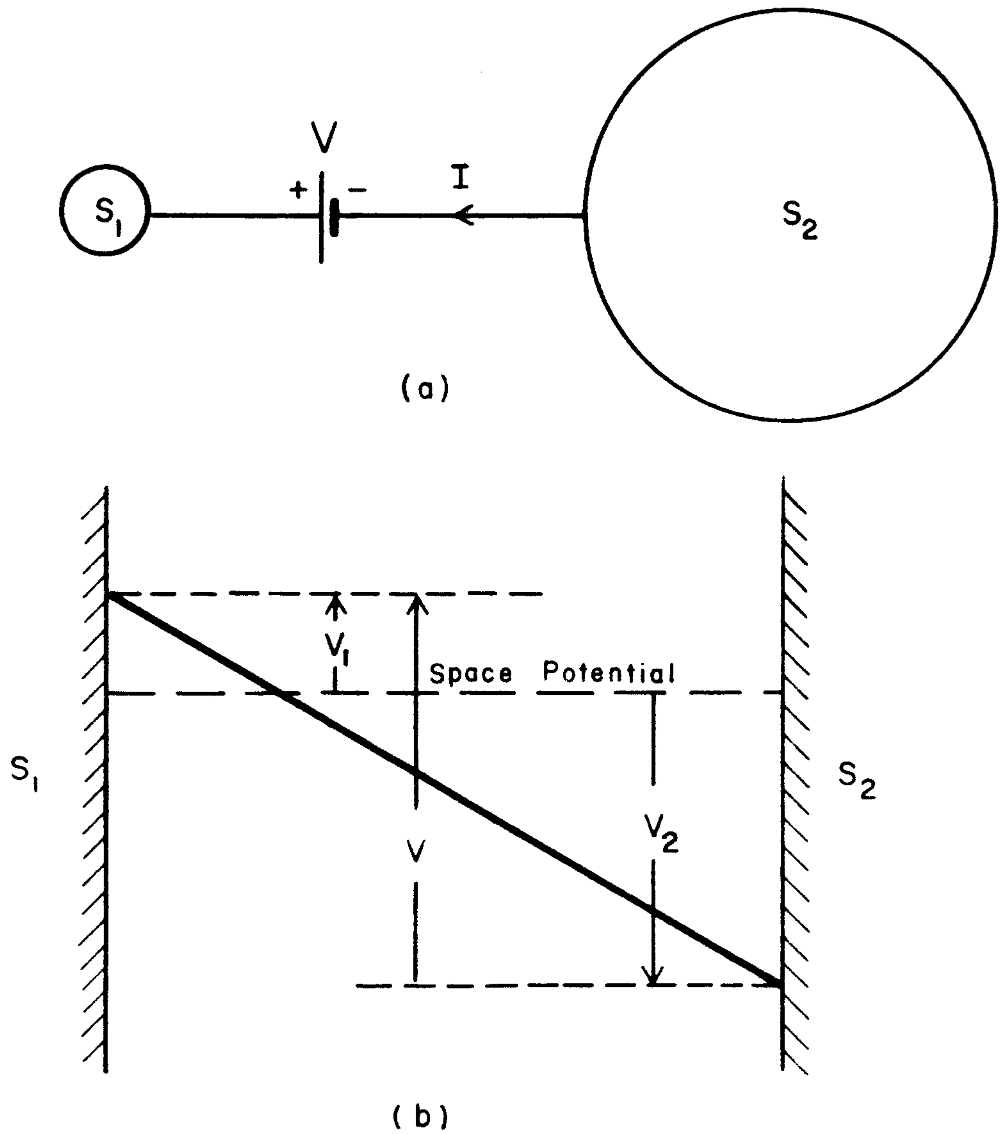
FIGURES



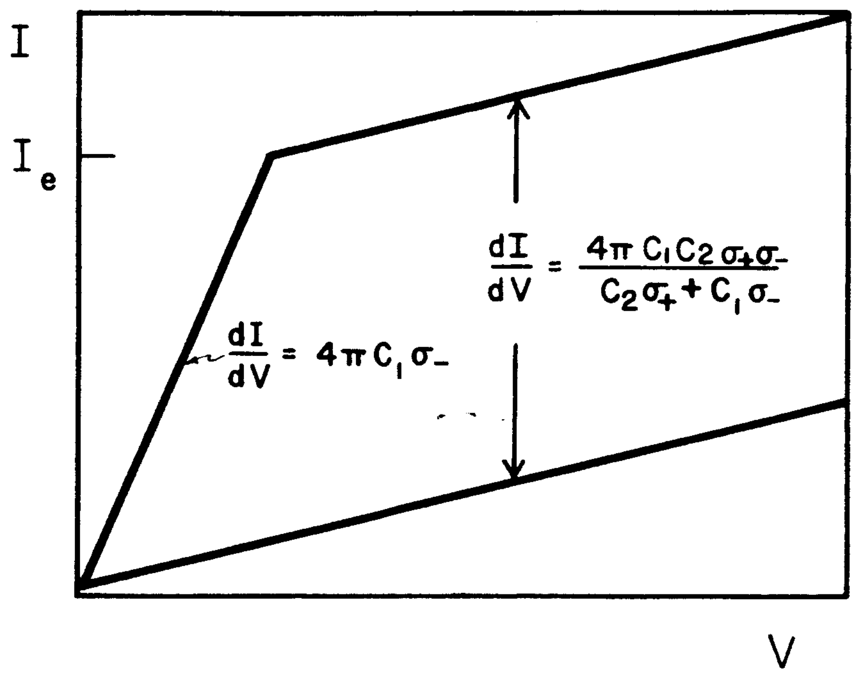
METHOD OF INSULATING NOSE ELECTRODE (ORIGINAL DESIGN)



METHOD OF INSULATING NOSE ELECTRODE (FINAL DESIGN)



Double probe measurement of
conductivity



Effect of photoemission on I – V plot